Universitat Autònoma de Barcelona

2020/2021

Quantum Information

Code: 104408
ECTS Credits: 6

Degree	Type	Year	Semester
2503740 Computational Mathematics and Data Analytics	OB	3	2

The proposed teaching and assessment methodology that appear in the guide may be subject to changes as a result of the restrictions to face-to-face class attendance imposed by the health authorities.

Contact

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Use of Languages

Principal working language: catalan (cat)
Some groups entirely in English: No
Some groups entirely in Catalan: Yes
Some groups entirely in Spanish: No

Teachers

Ramón Muñoz Tapia

Prerequisites

It is advisable to have a good command of algebra, especially of vector spaces and, preferably, of complex Euclidean spaces. It is advisable also to be familiar with the basic concepts of classical information, as delivered in the course "Teoria de la informació" of the first semester.

Objectives and Contextualisation

The course is an introduction to the current view of quantum mechanics and its paradigms. With the technology we have today, many of the most paradoxical quantum effects have ceased to be an academic curiosity and have become very powerful resources that will be the basis of many amazing practical applications in the not too distant future. This course introduces some of them: teleportation, dense coding, Bell inequalities, cryptography, quantum computing, and more. The course is aimed at mathematicians with a strong vocation for data analysis, therefore, it will be necessary to provide essential physical training with an introduction to the fundamentals of quantum mechanics, classical cryptography and computing. The basic concepts of classical information theory are also reviewed. The course has a strong computational component, numerical simulations of various phenomena will be done and prototypes of quantum computers will be used to program various protocols. The aim of the subject is not only to give a description of the advances that have taken place in quantum information, but also to provide the student with the basic tools to be able to continue his postgraduate training in this field, if this is their interest.

Competences

- Demonstrate a high capacity for abstraction and translation of phenomena and behaviors to mathematical formulations.
- Make effective use of bibliographical resources and electronic resources to obtain information.
- Plan and carry out studies of physical system using analytical or numerical methods and interpret the results.

- Students must be capable of applying their knowledge to their work or vocation in a professional way and they should have building arguments and problem resolution skills within their area of study.
- Students must be capable of collecting and interpreting relevant data (usually within their area of study) in order to make statements that reflect social, scientific or ethical relevant issues.
- Students must have and understand knowledge of an area of study built on the basis of general secondary education, and while it relies on some advanced textbooks it also includes some aspects coming from the forefront of its field of study.
- Using criteria of quality, critically evaluate the work carried out.

Learning Outcomes

1. Apply the concept of quantum measurement to problems of optimising simple problems in quantum discrimination, estimation and communication.
2. Explain the postulates of quantum physics and apply these to information-processing problems.
3. Make effective use of bibliographical resources and electronic resources to obtain information.
4. Master the Dirac and matrix principles and formalism of quantum physics.
5. Students must be capable of applying their knowledge to their work or vocation in a professional way and they should have building arguments and problem resolution skills within their area of study.
6. Students must be capable of collecting and interpreting relevant data (usually within their area of study) in order to make statements that reflect social, scientific or ethical relevant issues.
7. Students must have and understand knowledge of an area of study built on the basis of general secondary education, and while it relies on some advanced textbooks it also includes some aspects coming from the forefront of its field of study.
8. Understand the impact of quantum technologies in computing, cryptography and other communication protocols.
9. Using criteria of quality, critically evaluate the work carried out.

Content

0. Review of probability and information

- Conditional probabilities
- Entropy and information
- Communications theory

1. Elements of quantum theory

- Basic principles
- Mixed states
- Unitary operators
- Qubits
- Entangled states
- von Neumann measurement

2. Generalized measurements

- Generalized measurements
- Optimized measurements
- Operations

3. Quantum cryptography

- Information security
- Quantum communications
- Quantum key Distribution

4. Entanglement

- Non-locality
- Indirect measurements
- Ebits and shared entanglement
- Quantum dense coding
- Teleportation

5. Quantum information processing

- Digital electronics
- Quantum gates
- Quantum circuits
- Quantum error correction

6. Quantum computation

- Elements of computer science
- Principles of quantum computation
- Deutsch-Jozsa algorithm
- Grover's search algorithm
- The quantum Fourier transform
- Shor's factoring algorithm
- Physical requirements

7. Quantum information theory

- The von Neumann entropy
- Compression Theorem
- Accessible information
- Composite systems
- Measures of entanglement
- Quantum communications theory

Methodology

The course is structured into theory lectures, exercises lectures, and continuous assessment activities.

The theory lectures are in keynote/powerpoint presentation format. There will be some classes/seminars on some course topics that will be presented by researchers in the field of Quantum Information. These seminars will generally be in English.

The exercises lectures are usually made on the blackboard and consist of solving the most significant problems, the statements of which are made available to students through the Virtual Campus.

There will be 4 deliveries. The objective is to deepen, consolidate and extend the students' knowledge about aspects and results explained throughout the course. Thus, the deliveries may contain problems and issues of greater complexity and extension. These should be delivered periodically throughout the course and on previously agreed dates. The aim of these activities is to encourage autonomous work.

All the material: lists of problems, additional teaching material, detailed resolution of some exercises, as well as news related to the course, are made available to the students through the Virtual Campus.

Activities

Title	Hours	ECTS	Learning Outcomes
Type: Directed			
Seminars of specific topics	10	0.4	8

Theoretical lessons	28	1.12	8, 2, 3
Type: Supervised			
Projects with online quantum computers	12	0.48	9, 8, 2
Type: Autonomous			
Homework exercises	36	1.44	1, 9, 8, 4, 3
Numerical resolutions of excercises	36	1.44	1, 9, 8, 6, 3
Study of the theoretical background	20	0.8	1, 8, 2, 6, 3

Assessment

The evaluation consists of the following activities

1. A test of theoretical concepts, with a weight of 45%
2. A test on computational aspects with a weight of 20%
3. Delivery of exercises performed autonomously throughout the course, with a weight of 30%
4. Attendance and active participation in specific seminars to be held during the course, with a weight of 5%

Students who have been assessed in at least 66% of the total activities may take the rehearsal tests for activities 1 and 2. A student who has only completed activities 3, 4 will be considered non-assessable.

Assessment Activities

Title	Weighting	Hours	ECTS	Learning Outcomes
Assessment of computational aspects	20	1.5	0.06	8, 4, 7, 5, 3
Attendance and participation in specialized seminars	5	0	0	1, 8, 4, 2, 7, 5, 3
Delivery of exercises (autonomous work)	30	0	0	1, 9, 8, 4, 5, 6, 3
Evaluation exam of theoretical concepts	45	2.5	0.1	1, 8, 4, 2
Retaken exam of theoretical and computational aspects	45	4	0.16	1, 8, 4, 2, 3

Bibliography

The students wil have access to the lessons in pdf format and copies of the Keynote / Powerpoint of the course. For further information, the following bibliography is advisable:

Theory

- S.M. Barnett, Quatum Information, Oxford University Press, 2009.
- J. Preskill. Lectures notes on Quantum Computation. Es pot obtenir gratuïtament a la direcció: http://www.theory.caltech.edu/people/preskill/ph229.
- M.A. Nielsen; S.L. Chuang. Quantum Computation and Quantum Information. Cambridge Univ. Press, Cambridge 2000.

• A. Peres. Quantum Theory: Concepts and Methods. Kluwer, Dordrecht 1995.
• D. Applebaum. Probability and Information. Cambridge Univ. Press, Cambridge 1996.
• D. Boumeester; A. Eckert; A. Zeilinger. The Physiscs of Quantum Information. Springer 2000.
• D. Heiss. Fundamentals of Quantum Information. Springer 2002.

Problems

- Steeb, Willi-Hans, and Yorick Hardy. *Problems and solutions in quantum computing and quantum information*. World Scientific Publishing Company, 2018.
- C. P. Williams; S. Clearwater. Exploration in Quantum Computing. Springer 1998